Security Principles and Practices in Midori

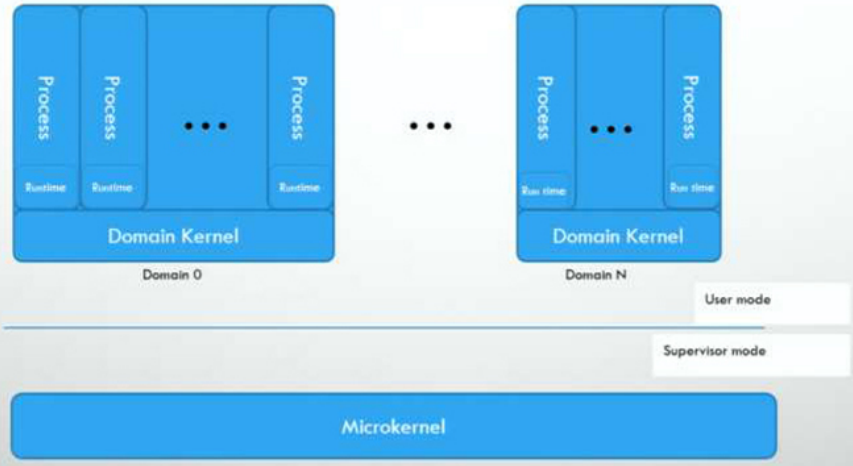
Jinsong Yu

January 2014

BRIEF HISTORY OF MIDORI

- System Incubation Effort
- First sprint dated 2006
- Singularity heritage
- Joined OSG in late 2013

SYSTEM OVERVIEW



1. PERVASIVE MANAGED CODE

- Vast majority of the system is written in safe M# code
  - M# language is C# augmented to add immutability and concurrency safety guarantees
- C/C++, ASM, unsafe M# used in a few places:
  - Bottom layers: entire microkernel, part of domain kernel, GC and part of runtime.
  - Unmanaged code we picked up and plan to use in long term: Enigma, ACPI.
  - Unmanaged code we picked up as scaffolding: some multimedia components.

IMPLICATIONS

- Memory safety and type safety
- No buffer overrun, and heap/stack corruption
- No double-free
- No use-after-free
- Allows software-isolated-processes

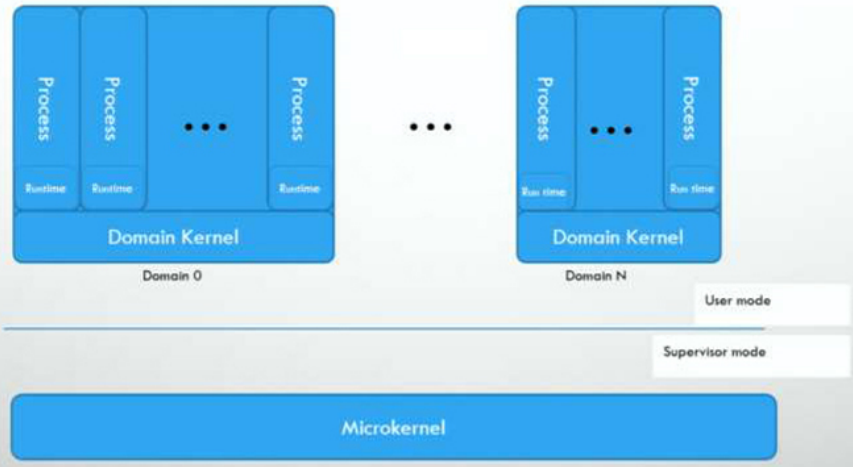
2. CLOSED PROCESSES

- All code in a process is known at compile time and loaded before the process starts.
- No dynamic DLL loading (LoadLibrary)

Implications

- Allows comprehensive compile-time and installation-time checking
- Enables capability based security model (more details later)
- Removes certain run-time failure modes

SYSTEM OVERVIEW



2. CLOSED PROCESSES

- All code in a process is known at compile time and loaded before the process starts.
- No dynamic DLL loading (LoadLibrary)

Implications

- Allows comprehensive compile-time and installation-time checking
- Enables capability based security model (more details later)
- Removes certain run-time failure modes

3. STRICT ERROR MODEL – CHECKED ARITHMETIC

- Checked arithmetic by default, overflow causes immediate process termination

```
bool IsValidRange(uint start, uint count, uint bound)
{
    return start + count <= bound; // terminates if start+count overflows
}
```

- Use unchecked keyword to override

```
bool IsValidRange(uint start, uint count, uint bound)
{
    uint end = unchecked(start + count);
    return end >= start && end <= bound;
}
```

- Same applies to number conversions and divide by 0.
- Helper functions TryAbs(), TryDiv(), etc.

3. STRICT ERROR MODEL - PRECONDITIONS

- Precondition errors cause immediate process termination

```
public void SetCapacity(int count)
        requires count > 0
{ ... }
```

- Preconditions are part of API signature
- Callers are responsible to sanitize parameter values
- TryFoo(…) pattern for parsers and decoders

3. STRICT ERROR MODEL – NO OUT-OF-BAND EXCEPTIONS

- No dynamic DLL loading, therefore no BadImageFormatException
- No threads therefore no ThreadAbortException
- Out-of-memory causes immediate process termination
- Stack overflow is same as out-of-memory
- Array bound check error causes immediate process termination
- Dereferencing NULL causes immediate process termination
- Access violation (non-NULL) causes immediate domain termination

- All exceptions are thrown by “throw” statements in the code

3. STRICT ERROR MODEL - DECLARED EXCEPTION

```
public throws int Foo(int count) { ... }

void Bar() {
    int a = Foo();      // compile error, exceptions not handled
    int b = try Foo(); // compile error, attempt to propagate
                       //    exception while Bar() is not "throws"
    try { int c = Foo(); } catch { ... }    // OK
    Result<int> d = trycatch Foo();         // OK
}

throws void Bar() {
    int b = try Foo();  // OK, propagates exception up
}
```

IMPLICATIONS

- Defaults to strict behavior
- Prefers deterministic process termination over continue running with inconsistent state
- Easier to DoS, harder to go beyond DoS
- Easier to diagnose

- All exceptions are explicitly declared and thrown
- Callers of “throws” code must explicitly handle or propagate exceptions
- Hard to ignore exceptions
- Preconditions and throws are part of API signature and therefore versioning story

4. NO SHARED MUTABLE MEMORY CROSS PROCESS BOUNDARY

- Memory shared among different processes must be immutable, guaranteed by type system and compiler.
- Mutable memory is always exclusively owned

Implications

- No TOCTOU issues cross process boundary
- Hard for a process to exploit bugs in another process

5. CONCURRENCY SAFETY – NO THREADS

- Public APIs don't contain any of these:
  - CreateThread()
  - Lock, Semaphore, AutoResetEvent, Monitor, …
  - InterlockedCompareExchange
- Achieve concurrency by:
  - Decompose or scale out to multiple processes
  - Use safe data-parallelism and task-parallelism APIs
- No instruction-level thread interleaving concerns
- Interleaving only happens at "turn" boundary, which is clearly visible in source code

5. CONCURRENCY SAFETY - EXAMPLE

```
throws awaits void FinishPOST(HttpRequest request,
        HttpResponseBuilder response, string filePath, uint myCookie)
{
    string cookieStr = StringConverter.Invariant.FormatUInt32(myCookie);

    Stream stream;
    try {
        stream = (try await GetFileContents(m_rootStatic, filePath)).Extract();
    }
    catch {
        try await WriteErrorResponse(request, response, HttpStatusCode.NotFound,
                  "Couldn't open file: " + filePath);
        return;
    }

    response.SetCookie("my_cookie=" + cookieStr);
    try await WriteFileResponse(request, response, in stream);
}
```

5. CONCURRENCY SAFETY – TSE

- Language features to guarantee deep immutability of an object graph:
  - immutable / readable / writable / isolated
- Only immutable objects can be shared across data-parallelism and task-parallelism boundaries
  - Corollary: all static fields are immutable
- Allows fine-grained reasoning of state invariants and state changes in the code

IMPLICATIONS

- No instruction level thread interleaving concerns
- No TOCTOU and races cross data-parallelism and task-parallelism boundary
- State interleaving only happens at turn boundary in a single-threaded fashion
- TOCTOU inside the same execution unit is easy to reason about
- Language and compiler helps reasoning about state changes

6. CAPABILITY BASED SECURITY MODEL

- Capability vs. ACL
- ACL example:

```
void Foo()
{
    File f = File.Open("c:\\windows\system32\a.txt");  // May fail due to access denied
    ...
}
```

- Capability example:

```
void Foo(File f)
{
    ...
}
```

6 CAPABILITY BASED SECURITY MODEL

- Consuming CPU and Memory resources does not require a capability
- All other resource consumption requires capability. No static methods to access resources
- None of these exists:
  - File.Open(), File.Create(), …
  - DateTime.Now(), CTime::GetCurrentTime(), …
  - Process.GetProcessByName()
- Capability provisioning rolls all the way up to process entry point
  - For program entry point, capabilities are supplied by the system, controlled at installation time
  - For child processes, capabilities are supplied by the parent process

6 CAPABILITY BASED SECURITY MODEL - EXAMPLE

```
sealed class PerfInfo : AShellAddin
{
    [Remotable(IsProgram = true)]
    public PerfInfo(
        PerfCounterProviderRepository directory,
        SystemPerfCounterQuery systemPerfCounterQuery,
        ProcessPerfCounterQuery processPerfCounterQuery,
        ProcessInformation processInformation,
        AsyncFactory parentAsyncFactory,
        Clock clock)
    {
        ...
    }
    ...
}
```